A dual-band linear phased array antenna for WiFi and LTE mobile applications

A Dual-band Linear Phased Array Antenna for WiFi and LTE Mobile Applications

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***Abstract*— This paper presents a linear phased array antenna with beam steering capability designed for WiFi and LTE mobile standards. The proposed antenna array utilizes 4 elements of patch antenna arranged in a flat configuration. The antenna element used in the array exhibits dual band characteristic covering 2 wide frequency bands; 2.35 GHz to 2.8 GHz (lower band) and 5 GHz to 5.5 GHz (upper band). To excite dual resonances, a rectangular ring slot was cut in the ground plane of the rectangular patch. The upper patch acts as the feeding element for the rectangular ring slot for lower band operation and as a radiator at the upper frequency band. The simulation results show a bi-directional radiation pattern at the lower frequency band and unidirectional at the upper band. By varying the phase of the individual antenna elements, the main beam of the proposed linear array can be steered to a range of ±40° for the lower band and ±22° for the upper band with side lobe level (SLL) and half-power beam width (HPBW) less than -7 dBi and 43° respectively. The array is intended to be fed by a corporate feeding network using three wideband 3-port Wilkinson power dividers. A FR4 (1.6 mm) is used as the antenna substrate and the feeding element. The overall size of the proposed array and the feeding element is 155 mm × 35 mm × 1.6 mm and 155 mm × 83 mm × 1.6 mm respectively. The designs and simulations have been carried out using CST Microwave Studio. The presented array antenna can be particularly applied to small and portable mobile base stations.**

Keywords—Slot antenna, Patch antenna, Phase Array, WiFi, LTE

I. INTRODUCTION

Almost all commercial wireless communication devices produced today such as smartphones, tablets, laptops and wearable devices are required to support multiple communication standards such as WiFi, Bluetooth and LTE. The idea of Internet of Things where every communication device is connected together is being realized with a rapid development of new wireless standards with the aims of providing higher data speed, constant connectivity, and low implementation cost. In order to support existing wireless networks as well as future generation standards, such as 5G, research towards smart and efficient antenna configurations is vital.

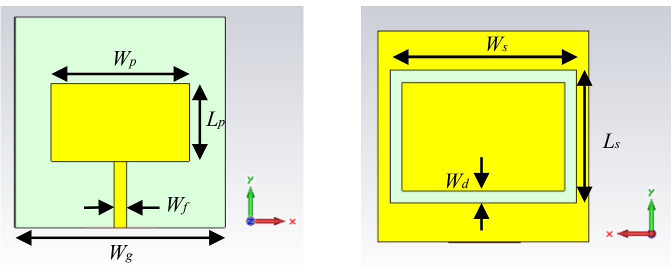
Numerous research papers on antenna design in the literature have covered different types of applications ranging from communication to identification and detection applications. Several compact multiband antenna designs have been proposed to be used in mobile phones in [1][2]. The compact and multiband features of the proposed designs are the main characteristics required for wireless devices. A reconfigurable type antenna is presented in [3][4] to reduce the numbers of antenna elements in the system, hence giving way to a low cost components and reducing the overall size. Apart from the mentioned antenna, progress in antenna design for mobile base stations is of paramount important to the overall performance of the communication system. The mobile base station and wireless router are required to provide better coverage in order to serve as many mobile users as possible with high data rate and without any interruption so that a better experience can be provided. The antenna used in those systems must have high gain and high efficiency to ensure the consumers are well served.

One of the methods to improve the performance of an antenna is to synthesize an antenna array. It is well known that by combining several antennas in an array configuration, its performance is increased tremendously as compared to a single element [5]. Some of the advantages of an antenna array are high gain, high directivity, and ability to provide scanning capability. The integration of the phase shifter in the array offers a steering capability of the antenna's main lobe hence making it more efficient and consume less power. Numerous projects in phase array antennas can be found in the literature especially for radar and satellite applications [6][7]. There are several efforts to apply the array concept towards mainstream mobile standards such as WiFi and LTE. An 8 elements array configuration implemented in 3 faceted array structure was presented in [8]. The antenna array is designed to work at operating frequency of 2.5 GHz. It has been shown that this array configuration was able to improve the scanning angle of the antenna compared to a curve and 2 faceted implementation. However, the use of 8 elements in the array as well as its limited bandwidth makes its unsuitable to be used as an antenna in multi band compact wireless routers. A meandered loop antenna with omni-directional coverage was presented in [9]. However, the operating frequency of the proposed array is limited to WiFi application due to its narrow bandwidth. A bi-directional monopole array antenna covering both WiFi and LTE standards was proposed in [10]. The antenna array was designed to cater a long and narrow path service area such as long hallways, corridors and tunnel. However, scanning capability of both of the array were not reported.

In this research, a linear phased array antenna that consists of 4 dual band antenna elements capable of supporting several wireless communication bands such as WIFI, Bluetooth and LTE is proposed. The numbers of the elements used is kept at minimum in order to realize a small planar phased array antenna for mobile base stations and wireless routers. The antenna elements were fed with different phase to evaluate their beamforming performance. Based on the simulation results, the proposed antenna design is able to provide a scanning angle of around ±40° at lower band and around ±22° at higher band when a progressive phase shift is applied to each of the element. The half-power beam width (HPBW) of the main lobe and the side lobe level (SLL) are kept at below 43° and -7 dB throughout the scanning angle. A wideband corporate feed network was also designed and simulated. The simulation results show that the feeding element is suitable to be used with the proposed phased array antenna. However, the integration of the antenna array and feeding network was not carried out in this work. For future work, a suitable phase shifter will be used to implement the overall smart antenna system.

II. ANNTENNA DESIGN

The linear phased array antenna design starts with the development of a single antenna element. The antenna is derived from a patch antenna structure where a rectangular ring slot was cut on the ground plane to excite a wideband resonance at the lower operating frequency band as shown in Figure 1. The utilization of the ring slot rather than a typical patch antenna is to realize a wideband performance. The slot was fed by the top rectangular patch with narrow microstrip line extending from the center patch towards the bottom edge of the antenna. The top patch also acts as a radiating element at the upper frequency band like a typical microstrip antenna [11]. The dimension of the top conductor is slightly smaller than the outer dimension of the slot ring structure. The use of edge feed configuration will deliver a planar configuration and provide easy integration with a phase shifter and the proposed planar corporate feeding network in an array configuration. The dimension of the slot is calculated based on the half wavelength structure at the operating frequency of 2.4 GHz. The overall size of the antenna was kept to be as small as possible at 35 mm × 35 mm using a low cost FR-4 substrate of thickness 1.6 mm. The relative dielectric constant and loss tangent of the substrate are εr=4.4 and δ=0.02 respectively. The antenna design and parametric optimization of the antenna parameters were conducted using commercial electromagnetic simulator, CST. The optimal dimension of the proposed antenna is tabulated in Table I. The simulated reflection coefficient of the antenna is shown in Figure 2. Furthermore, the gain of the antenna at the direction normal to the antenna structure and its radiation efficiency were also simulated and illustrated in Figure 3 and Figure 4.



(a) (b)

Fig. 1. The geometry of the proposed antenna (a) Top view (b) bottom view

Based on Figure 2, it can be observed that there are two main operating frequency bands which are from 2.35 GHz to 2.8 GHz (lower band) and from 5 GHz to 5.5 GHz (upper band). These operating frequency bands cover WiFi (2.45GHz/5.3GHz), Bluetooth (2.45 GHz) and LTE (2.6 GHz) applications. From Figure 3, we can see that the antenna yields considerable antenna gain values. These are 2.53 dBi at 2.45 GHz, 2.6 dBi at 2.6 GHz and 4.2 dBi at 5.3 GHz considering the overall size and thickness of the antenna. As for its radiation efficiency, a good performance is shown across the operating bands. These are 93% at 2.45, 92% at 2.6 GHz and 74% at 5.3 GHz. The radiation pattern of the antenna is given in Figure 4 for both E-plane and H-plane at three main operating frequencies.

TABLE I. ANTENNA PARAMETER

Parameter	Value (mm)
Wg	35
Wp	23
Lp	13
Ws	31
Ls	22
Wd	2
Wf	2

III. PHASED ANTENNA ARRAY CONFIGURATION

Using the synthesized single antenna element from the previous section, a 4 elements linear phase array antenna is realized as shown in Figure 5. The antenna elements are arranged in linear configuration with spacing, *D*. The optimal spacing was chosen by varying the parameter in the simulation and the results were compared. The main requirements of the phased array antenna are narrow beam width, high gain, and low side lob level while achieving the highest scanning angle possible. The radiation pattern of the linear array configuration is given by [12]

$$S(\theta) = f(\theta)\sum_{i=1}^{K} a_i e^{j(K-i)kD\sin(\theta)} \tag{1}$$

where $f(\theta)$ is the antenna element pattern, k is the wave number, K is the total number of elements and a_i is the weighting factor of the individual element.

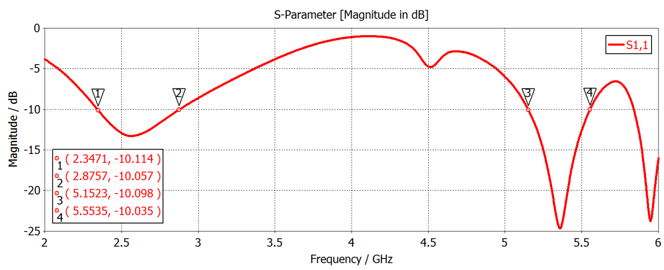


Fig. 2. Simulated reflection coeffecient

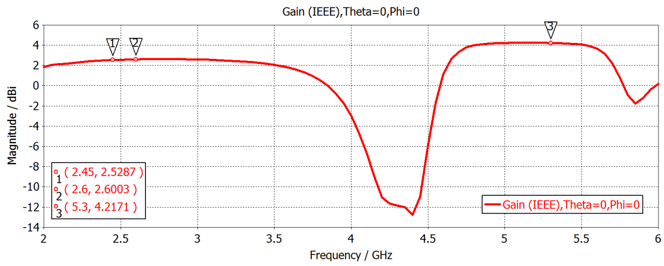


Fig. 3. Simulated peak gain of the antenna

In this design, the weighting factor of the elements is considered to be equal. The angle of the main beam of the array can be controlled by varying the progressive phase between the antenna elements. The scanning angle of the antenna calculated in (2) is mainly limited by the formation of grating lobe whose power level is comparable to the main lobe thus jeopardizing the overall performance of the phased array antenna. In order to find the optimal value of the inter-element spacing of the proposed array, three different values are used in the simulation which are 35mm, 40 mm and 50 mm. Then, each of the elements is fed with different phase to evaluate its scanning angle capability. The simulation results are then analyzed and compared. The performance is compared based on the return loss, maximum gain, maximum scanning angle, side lobe level (SLL) and mutual coupling.

$$\beta = kD\sin(\theta) \tag{2}$$

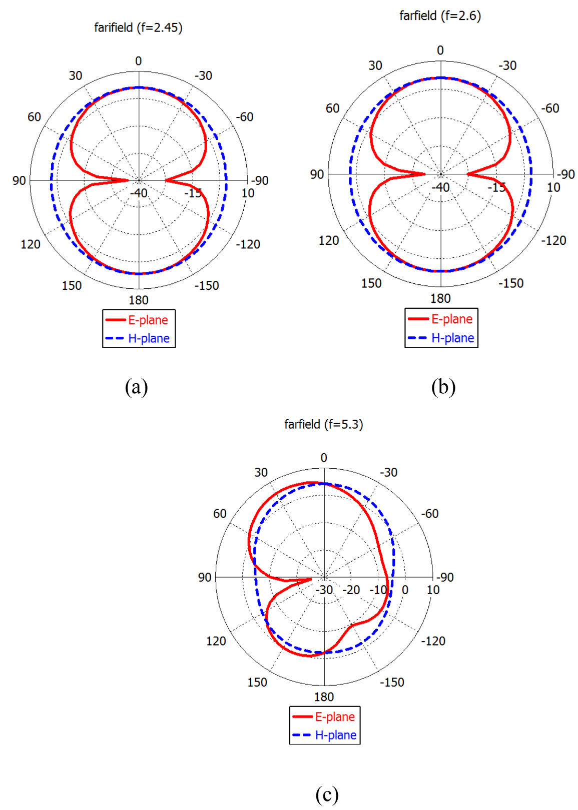


Fig. 4. The radiation pattern of the antenna at (a) 2.45 GHz, (b) 2.6 GHz and (c) 5.3 GHz

Since the antenna element exhibits dual band characteristics, the radiation properties at 3 main operating frequencies are investigated. For brevity, only the results for the optimal antenna spacing which is D=40 mm is provided as shown in Table II, Table III and Table IV. It can be seen from the tables that the maximum scanning angle at lower band (2.45 GH and 2.6 GHz) is about ±40° while at upper band (5.3 GHz) is ±22°. The large difference of the scanning angle at both frequency bands is due to the same applied phase, β at the antenna input.

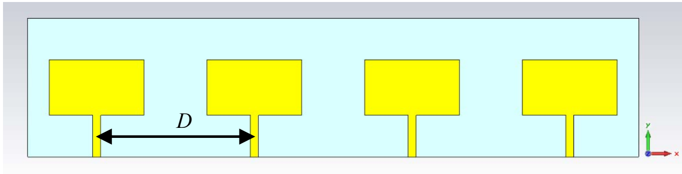


Fig. 5. Simulated peak gain of the antenna

TABLE II. RADIATION PROPERTIES OF LINEAR PHASED ARRAY AT 2.45 GHZ

Calculated Steered Angle (^{0})	Simulated Steered Angle (^{0})	HPBW (^{0})	SLL (dBi)	Gain (dBi)
0	0	36.3	-10.79	8.367
10	10	36.8	-10.015	8.3634
20	20	37.5	-9.09	8.1804
30	28.9	38.6	-8.45	7.6498
40	36	40.4	-7.94	6.9496
50	45	42.6	-7.35	6.0291
60	52	45.2	-6.56	4.7922

TABLE III. RADIATION PROPERTIES OF LINEAR PHASED ARRAY AT 2.6 GHZ

Calculated Steered Angle (^{0})	Simulated Steered Angle (^{0})	HPBW (^{0})	SLL (dBi)	Gain (dBi)
0	0	34.3	-10.914	7.85
9.42	9.87	35	-10.529	7.77
18.63	15.051	35.9	-9.8558	7.67
28.11	25.048	36.7	-9.5537	7.46
37.37	30.048	38.3	-8.8809	7.24
46	35.055	39.9	-8.36	6.89
54.54	40.142	41.8	-7.72	6.42

TABLE IV. RADIATION PROPERTIES OF LINEAR PHASED ARRAY AT 5.3 GHZ

Calculated Steered Angle (^{0})	Simulated Steered Angle (^{0})	HPBW (^{0})	SLL (dBi)	Gain (dBi)
0	0	17.9	-13.9	9.78
4.65	4.94	18.1	-12.9	9.7
9.11	9.36	18.1	-11.98	9.36
13.5	13.381	18	-10.918	8.93
17.5	15.062	18.5	-10.9	8.34
20.87	20.327	19.2	-10.76	7.52
23.81	22.56	19.5	-10.7	6.92

IV. ARRAY FEEDING ELEMENT

A wideband 3-port Wilkinson power divider is designed to operate at a frequency of between 2 GHz to 6 GHz so as to cover the target operating bands of the phased array antenna. It has been shown in [13] that the bandwidth of the Wilkinson power divider can be enhanced by cascading several segment of the quadrature. To improve the performance and simplify the design of the power divider, a tapered configuration is used [14]. The proposed power divider was optimized to realize the scattering parameter as shown in (3) [15]

$$S_{ij} = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} \tag{3}$$

where S_{11}, S_{22}, S_{33} (return loss) and S_{23}, S_{32} (isolation) are 0 while S_{12}, S_{21}, S_{13}, S_{31} (insertion loss) are $-j/\sqrt{2}$.

The resistive loads used in the design are 100Ω, 180Ω, 240 Ω. The final design of the wideband Wilkinson power divider is shown in Figure 6. The substrate used in the design is the same as that used for the antenna. FR-4 is used to facilitate an easy integration between the two components. Figure 7 illustrates the simulated S-parameters of the single 3-port Wilkinson power divider. It can be clearly seen that the operating bandwidth of the proposed power divider is from 2 GHz to 6 GHz covering both operating frequencies of the proposed antenna. To feed 4 elements phased array antenna, three wideband Wilkinson power dividers are combined together as shown in Figure 8. The simulations of the devised 4 port feeding elements were carried out to calculate scattering parameters as shown in Figure 9. Summary of the simulation results for both reflection and transmission coefficients for both feeding structures are shown in Table V and Table VI. The overall size of the design is 155 mm × 83 mm × 1.6 mm. Based on the results, the one to four wideband power divider shows good performance in terms of return loss, insertion loss and mutual coupling.

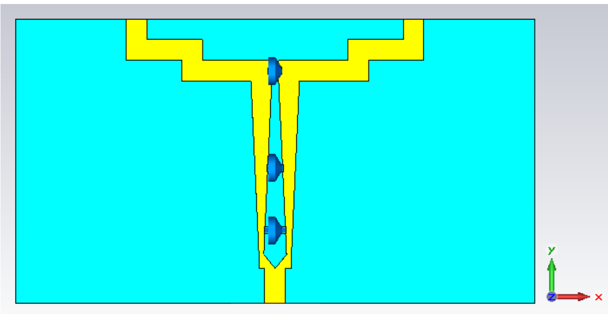


Fig. 6. Configuration of the single 3-port wideband power divider

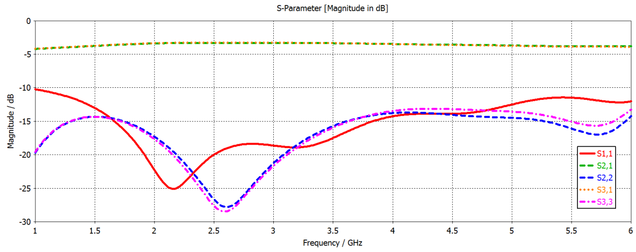


Fig. 7. Simulated reflection and transmission coefficient of single 3-way wideband power divider

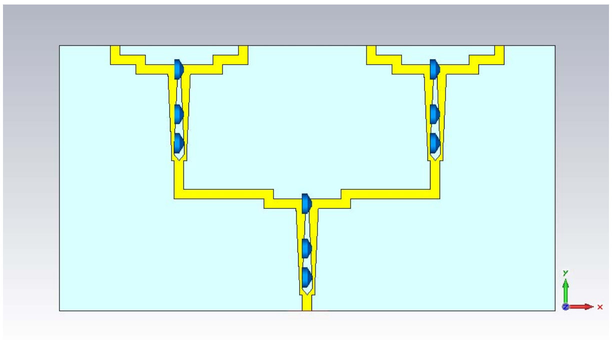


Fig. 8. Configuration of the one to four wideband power divider

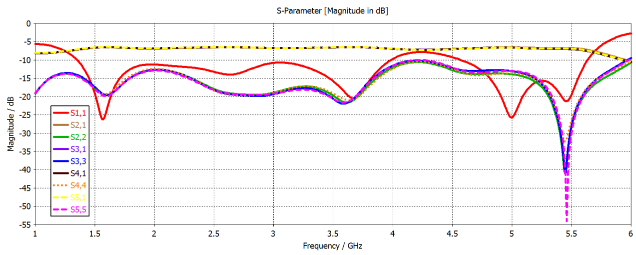


Fig. 9. Simulated reflection and transmission coefficient of one to four wideband power divider

I. CONCLUSION

In this work, a compact 4 elements linear phased array antenna with scanning capability is proposed for portable wireless application supporting WIFI and LTE communication standards. A wideband 3-way (equal) Wilkinson power divider is also designed to feed the proposed antenna array. A planar corporate feeding network is then realized using three power dividers. Overall size of the antenna array is 155 mm × 35 mm × 1.6 mm while the feeding element is 155 mm × 83 mm × 1.6 mm. The maximum scan angle of the antenna array is around 40° at lower band and 22° at upper band with SLL level less than -7 dB. The compact size of the array makes it suitable for use in the mobile base stations and wireless routers to serve mobile consumers in long hallways, corridors and tunnels. Future work will include integration of the antenna array, the proposed feeding network and a phase shifter to realize a complete phased array antenna with steerable beam angle for smart antenna applications.

TABLE V. SIMULATED S-PARAMETERS OF SINGLE WIDEBAND POWER DIVIDER

S-Parameter	2.45 GHz	2.6 GHz	5.3 GHz
S_{11} (dB)	-20.63	-19.09	-11.55
S_{22} (dB)	-25.61	-27.81	-15.1
S_{33} (dB)	-26.58	-28.46	-14.21
S_{21} (dB)	-3.3	-3.3	-3.77
S_{31} (dB)	-3.27	-3.27	-3.84
S_{23} (dB)	-18.77	-17.02	-15.06

TABLE VI. SIMULATED S-PARAMETERS OF ONE TO FOUR WIDEBAND POWER DIVIDER

S-Parameter	2.45 GHz	2.6 GHz	5.3 GHz
S_{11} (dB)	-12.84	-13.94	-16.02
S_{22} (dB)	-17.21	-18.93	-19.56
S_{33} (dB)	-17.47	-19.21	-18.77
S_{44} (dB)	-17.59	-19.44	-18.64
S_{55} (dB)	-17.56	-19.07	-17.95
S_{21} (dB)	-6.62	-6.56	-6.74
S_{31} (dB)	-6.57	-6.51	-6.95
S_{41} (dB)	-6.55	-6.50	-6.96
S_{51} (dB)	-6.54	-6.50	-6.89
S_{23} (dB)	-35.17	-22.99	-18.35
S_{34} (dB)	-24.62	-22.71	-20.08
S_{45} (dB)	-33.84	-22.82	-19.21

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